electromyographic (sEMG) signals. In the case of a 1-DOF system, for example, bicep and tricep sEMG signals can be used to command the elbow joint torque and in the case of a 3-DOF system, two additional degrees are added at the shoulder level, thus incorporating additional sEMG command signals from shoulder muscles.

[0079] An example of the exoskeleton arm includes seven degrees of freedom. The exoskeleton arm is actuated by seven DC brushed motors (Maxon) that transmit torque to each joint utilizing a cable-based transmission system. Four force/torque sensors (ATI-Nano 17) are located at all interface elements between the human arm and exoskeleton as well as between the exoskeleton and external load, measuring all forces and torques acting and reacting between the human arm, the external load, and the exoskeleton, as shown in FIG. **4**D. Elements illustrated in the figure include hand piece **130**, lower arm link **132**, circular bearing **134** for the lower arm, circular bearing **136** for the upper arm, upper arm link **138**, and actuators **140**.

[0080] FIGS. **4**A, **4**B and **4**C illustrate various joint configurations used in the exoskeleton of FIG. **4**D. The exoskeleton of FIG. **4**D includes various joints that achieve full glenohumeral, elbow, and wrist functionality. FIG. **4**B includes an illustration of hand piece **130**.

[0081] In one example, each force/torque sensor is a 6-axis sensor. In various examples, the sensor is a silicon strain gauge or a foil gauge. The exoskeleton is attached to a frame mounted on a wall, which allows adjustment of height and adjustment of the distance between the arms.

[0082] Articulation of the exoskeleton is achieved about seven single-axis revolute joints: one for each shoulder abduction-adduction (abd-add), shoulder flexion-extension (flx-ext), shoulder internal-external (int-ext) rotation, elbow flx-ext, forearm pronation-supination (pron-sup), wrist flx-ext, and wrist radial-ulnar (rad-uln) deviation. The exoskeletal joints are labeled 1 through 7 from proximal to distal in the order shown in FIG. **5**. FIG. **5** illustrates a model of exoskeleton axes in relation to a human arm. Positive rotations about each joint produce the following motions: 1) combined flx/abd, 2) combined flx/add, 3) int rotation, 4) elbow fix, 5) forearm pron, 6) wrist ext, and 7) wrist rad dev. Note that the order and orientation of some joints are different from the axes presented in FIG. **3**. Elements illustrated in FIG. **5** include hand piece **130**, lower arm link **132**, circular bearing **134** for the lower arm, circular bearing **136** for the upper arm, upper arm link **138**, and actuators **140**.

[0083] In one example, the exoskeleton joints are aligned with those of the human user. In particular, the rotational axis of the exoskeleton joint is aligned with the anatomical rotation axes. If more the one axis is involved at a particular anatomical joint (for example, the shoulder and the wrist), the exoskeleton joints emulating the anatomical joint intersect at the center of the anatomical joint. The glenohumeral (G-H) joint is modeled as a spherical joint having three intersecting axes. The elbow is modeled by a single axis orthogonal to the third shoulder axis, with a joint stop preventing hyperextension. Exoskeletal prono-supination takes place between the elbow and wrist joints as it does in the physiological mechanism. Two intersecting orthogonal axes represent the wrist. The range of motion of the exoskeleton joints support the ranges of motion encountered in most daily activities.

[0084] In the present subject matter, the human arm occupies a relatively large volume along the joint axis of rotation. This volume is to remain clear of obstacles and component configurations that could result in injury or discomfort to the user. Semi-circular bearings are used to allow users to don the device without strain or discomfort. The link adjacent to these semi-circular axes carries the mechanical components of the HMI. The mechanical HMI (mHMI) includes a pressure-distributive structural pad rigidly mounted to a six-axis force/torque sensor and is simultaneously securely fastened to the mid-distal portion of each respective arm segment. The fastening mechanism can include one or more straps made from one or more material (nylon, neoprene, metal), one or more wraps, or can include attachable or movable rigid components that partially or fully enclose the arm segment.

[0085] Those mHMI's that are placed high on the arm may produce unnaturally high forces through the interface points when operated in an assistive mode. In addition, compliance of the musculature in the proximal regions of the limb may contribute to compliance in the attachment, as well as variations in circumference potentially leading to further user discomfort. Cross-sections at distal parts of the limb segments are less variable in magnitude and thus experience reduced underlying skeletal transformation, making these locations better suited for mHMI attachment.

[0086] The exoskeleton includes an external structural mechanism with joints and links corresponding to those of the human body. In the case of the 7 DOF mechanism it includes 3 DOF for the shoulder joint 2 DOF for the elbow joint, and 3 DOF for the wrist joint (FIG. **4**). The anthropometrical mechanism has a reachable workspace that overlap the workspace of the human arm. The operator who wears the exoskeleton can reach any point in space that is reachable without it. As a powered mechanism, 7 actuators are incorporated into its structure supporting the 7 degrees of freedom. Four out of the seven actuators are located on a stationary base supporting the three degrees of freedom of the shoulderjoint as well as the flexionlextension of the elbow joint. Three actuators are located on the exoskeleton forearm actuating the forearm rotation as well as the two degrees of freedom of the wrist joint. The mechanism as a whole is actuated through cables transmitting the required torques from the actuators to each of the joints. The cable actuated approach allows some of the actuators to be placed in a stationary base such that the weight and inertia of the mechanism are minimized providing backdrivability and superior dynamics to the operator. Four multi-axes force sensors are located in all the human machine interfaces: handle, lower arm, upper arm and the tip of the mechanism where it interacts with the environment. A redundant sets of position sensors are distributed along the manipulator. Each joint (DOF) has two position sensors one (potentiometer) incorporated into the joint itself and another one (optical encoder) located on each one of the DC motors. A 32 channels EMG amplifier as well as 64 surface electrodes with various contact surface are incorporated into the system. The system is under the control of 2 PCs one of which is simultaneously used for real-time servo control as well as data acquisitions.

[0087] Anatomically, the lower arm (also referred to as the forearm, between the wrist and elbow) is able to twist along it's length in a manner that can be modeled in the exoskel-